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Microwave Integrated Circuit Amplifier Designs Submitted to Qorvo for Fabrication with 0.09-µm High-Electron-Mobility Transistors (HEMTs) Using 2-mil Gallium Nitride (GaN) on Silicon Carbide (SiC)

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Sensors and Electron Devices Directorate, ARL

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14. ABSTRACT

Microwave integrated circuits are essential for wireless communication and networking systems. At the high frequencies of approximately 30 to 45 GHz, monolithic microwave integrated circuits (MMICs) are essential for compact hand-held satellite communications systems that provide instant, secure data and voice links in remote global regions. Small, efficient electronic components are needed for these, often battery powered, communications systems. The US Army Research Laboratory has designed several high-performance circuits and submitted them to fabrication using a prerelease research 0.09-µm gallium nitride (GaN) process under a cooperative research agreement with Qorvo. GaN integrated circuits have significantly increased power densities for MMICs over previous technologies, such as gallium arsenide and other III/V devices. GaN devices also offer high-power survivability and robust performance for low noise receivers.

15. SUBJECT TERMS

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1. Introduction

Microwave integrated circuits are essential for wireless communication and networking systems. At the high frequencies of approximately 30 to 45 GHz, monolithic microwave integrated circuits (MMICs) are essential for compact hand-held satellite communications (SATCOM) systems that provide instant, secure data and voice links in remote global regions. Small, efficient electronic components are needed for these, often battery powered, communications systems. Recent US Army Research Laboratory (ARL) designs have concentrated on power amplifier circuits that are essential to SATCOM links, working to improve on power efficiency, bandwidth, and gain of MMICs using prerelease research processes for gallium nitride (GaN) integrated circuits. GaN integrated circuits have significantly increased power densities for MMICs over previous technologies, such as gallium arsenide and other III/V devices. GaN devices also offer high-power survivability and robust performance for low-noise receivers. Future work on next-generation radars will be focused on lower frequencies than the previous high-frequency SATCOM work but will again use the advantages of new device technologies and design approaches for broadband, efficient, adaptable, modular circuits for future Department of Defense systems.

ARL has been working with TriQuint Semiconductor Inc. (TQS), which is now part of Qorvo—the recent merger of TriQuint and RFMD. A cooperative research agreement (CRADA) between ARL and Qorvo (TQS) has provided GaN integrated circuit fabrication for ARL designs and ARL intellectual property. Previously, efforts focused on developing efficient high-power amplifiers for SATCOM applications, while current efforts are focused on modeling efforts, broadband robust front-end circuits, and other circuits across the full spectrum of front- and back-end communication MMICs. Several ARL-designed circuits were submitted for fabrication in Qorvo's prereleased 0.09-µm GaN on 2-mil SiC process. This technical note gives a brief overview of the designs submitted for fabrication, which will be followed by a more thorough technical report on the design details of these circuits.

2. Layout of GaN Die

Qorvo is developing a high-frequency, high-power, 0.09-µm, high-electron-mobility transistor (HEMT) GaN (GAN09) on a 2-mil-thick silicon carbide (SiC) integrated circuit process. Several one-stage power amplifiers for Ka-band (24 and 32 GHz) and Q-band (45 GHz) operation were designed at ARL using Qorvo's proprietary 0.09-µm GaN process. The designs primarily used a 4- × 50-µm or

6- × 50-µm HEMT cell using measured data and based on load pull data (8, 16, 24, and 32 GHz) measured at ARL. Simple one-stage designs with a single HEMT were designed for 24, 32, and 45 GHz. Qorvo offered to fabricate the amplifier designs by ARL on a single 2.7- × 2.0-mm die. This die site allowed for single-stage 4 × 50 Q-band amplifiers at 24, 32, and 45 GHz, single-stage 6 × 50 Q-band amplifiers at 32 and 45 GHz, a broadband distributed amplifier, and small broadband 2- × 40-µm, 4- × 50-µm, and 6- × 50-µm feedback amplifiers as shown in Fig. 1. For optimal performance of the amplifiers, it is desirable to size each die appropriately for the intended final package and to minimize wire bond parasitics.

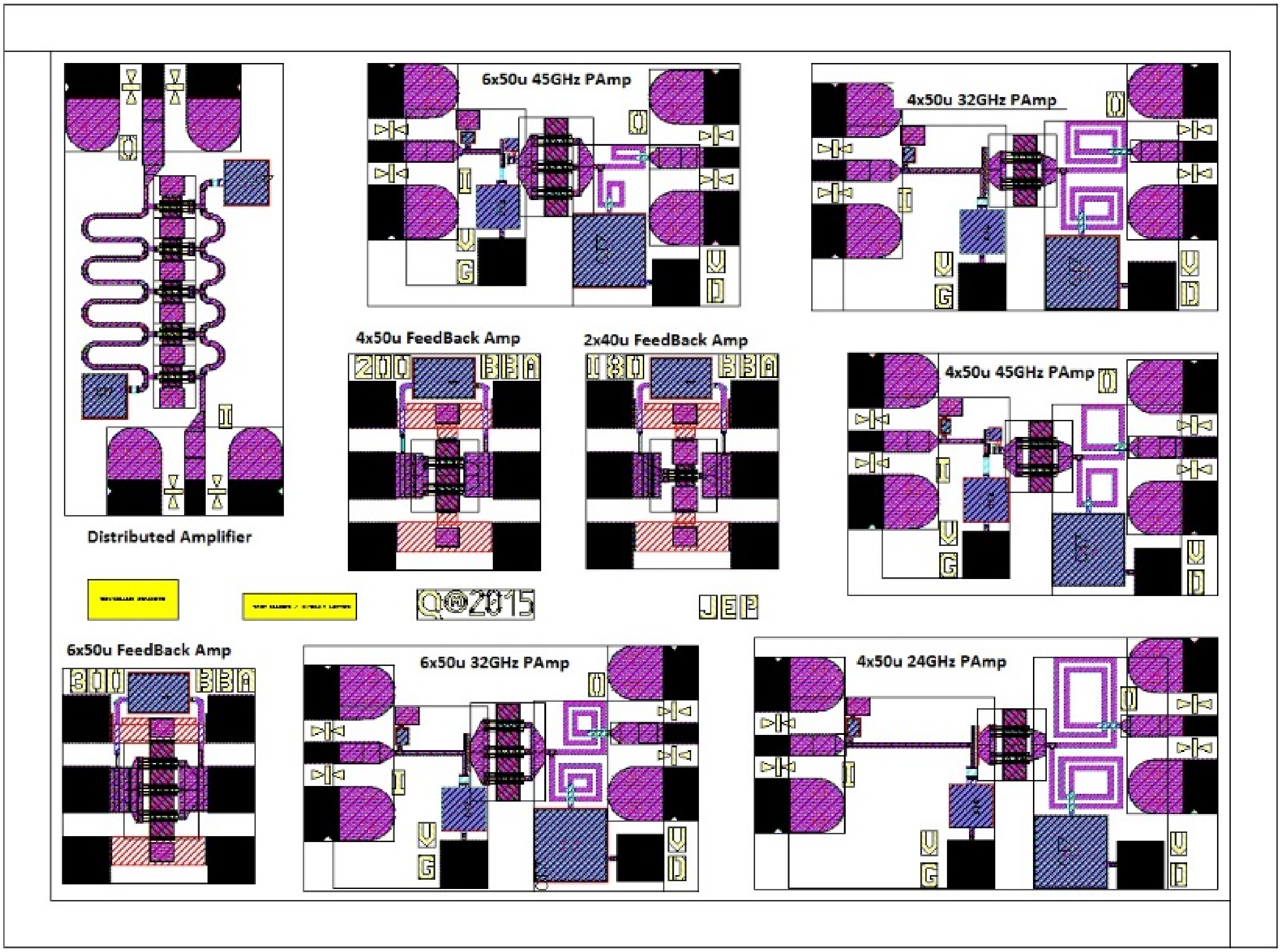

Fig. 1 CKT_ARL: broadband feedback amplifiers, one-stage power amplifiers (24, 32, and 45 GHz), and broadband distributed amplifier 2.7 × 2.0 mm

A few weeks later, a second available die site was offered, so additional designs were added to this second 2.0- × 2.0-mm die site. This die site allowed for a single-stage 6 × 50 Q-band amplifier at 24 GHz, a voltage-controlled oscillator (VCO) at 30 GHz, fixed oscillators at 40 and 60 GHz, a varactor HEMT test structure, a shunt HEMT switch test structure, and a broadband single-pull double-throw (SPDT) transmit/receive (T/R) switch as shown in Fig. 2.

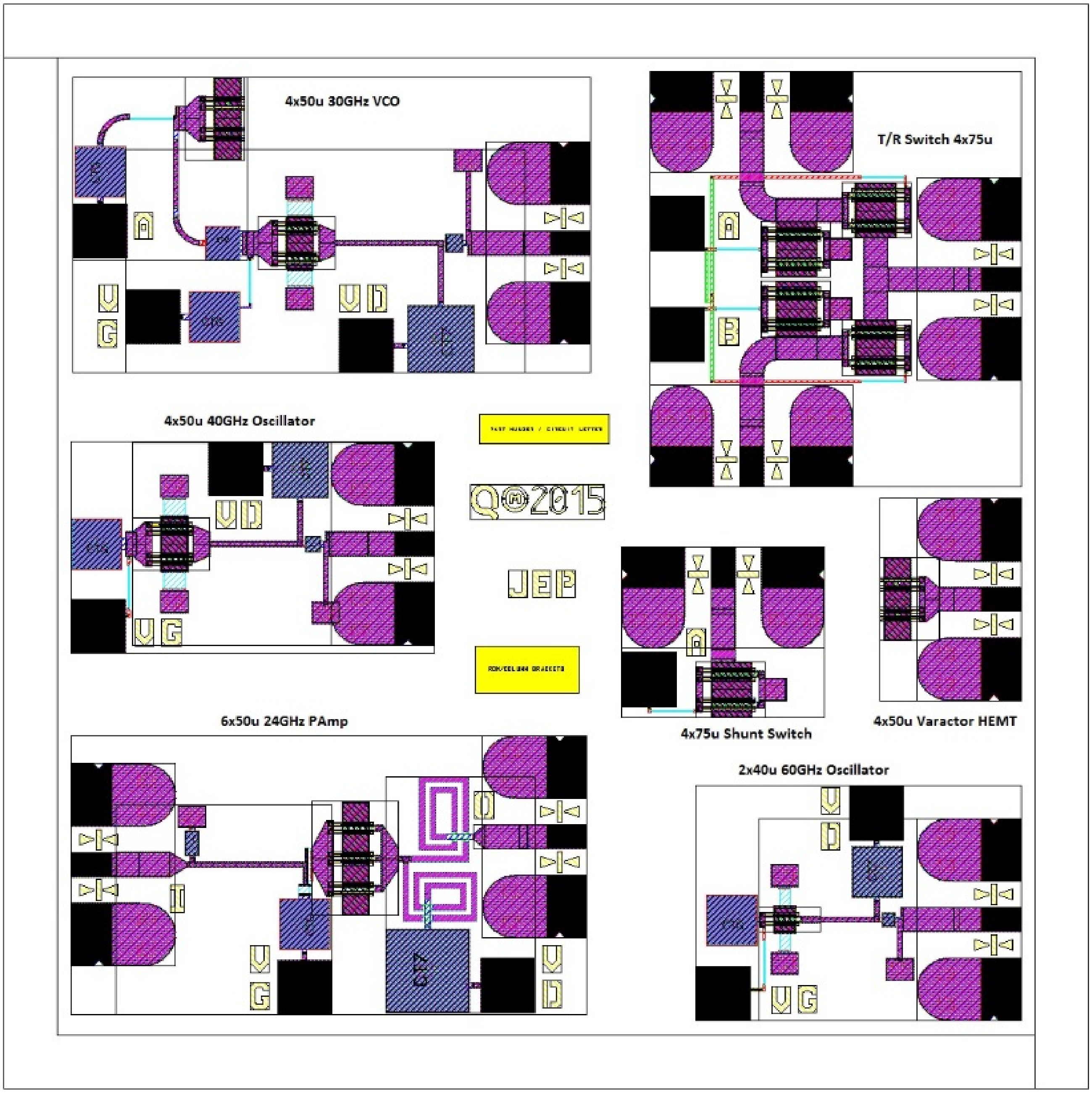

Fig. 2 CKT_ARL2: one-stage power amplifier 24 GHz, voltage-controlled oscillator 30 GHz, oscillator 40 GHz, oscillator 60 GHz, varactor HEMT, shunt HEMT switch, and SPDT T/R switch 2.0 × 2.0 mm

3. Summary of Designs

Following is a list of the amplifier designs in the die layouts:

- CKT_ARL: 4- × 50-µm, 24-, 32-, and 45-GHz power amplifiers (PAs); 6- × 50-µm, 32- and 45-GHz PAs; a 5-stage 2- × 40-µm broadband distributed amplifier; and a 2- × 40-µm, 4- × 50-µm, and 6- × 50-µm broadband feedback amplifier (2.7- × 2.0-mm die)
- CKT_ARL2: 6- × 50-µm, 24-GHz PA; a VCO at 30 GHz; fixed oscillators at 40 and 60 GHz; a varactor HEMT test structure; a shunt HEMT switch test structure; and a broadband T/R switch (2.0- × 2.0-mm die)

The amplifiers in CKT_ARL will be documented in separate technical reports. The feedback broadband amplifiers are similar to a design fabricated on 4-mil GaN on SiC, documented previously in ARL-TN-0497.[1] Additional circuits added in the second die site, CKT_ARL2, included oscillators and switch devices, which will be documented in a separate technical report.

4. Design Rule Checking (DRC)

Design rule checking (DRC) verifies all the layout information to provide for manufacturability. Checks for correct line widths, spacing between polygons within the masks, and checks for appropriate combinations of layers to ensure a successful design are performed with the DRC software and design rules—both provided by Qorvo. Since this design process is in development, the DRC rules are incomplete. Initially, the layouts were checked according to the process design rules supplied by Qorvo using a similar released process, Qorvo's 0.15-µm GaN process on 4-mil SiC. Qorvo also provided the critical physical layouts of the 4- × 50-µm and 6- × 50-µm HEMTs, and provided additional checking for their preliminary 0.09-µm GaN on 2-mil SiC process. Currently, they are integrating these ARL designs with their Qorvo internal and other external designs. There is still the possibility of an electrical error, even with a correct DRC check; however, these designs are relatively simple. Further, electromagnetic simulations of the designs based on the actual physical layout help to verify the correct connectivity of the passive elements, up to the HEMT connections. This is the first ARL submission in this unreleased TriQuint 0.09-µm GaN on 2-mil SiC process.

5. Summary

ARL designed and submitted to fabrication several single-stage GaN power amplifiers as well as several other interesting test devices and circuit designs that

would be useful in future compact, efficient communications systems. Qorvo Semiconductor will fabricate these designs under the CRADA between ARL and Qorvo. Once the designs are returned, they will be tested and documented in future reports. These will be the first designs from ARL using early access to Qorvo's high-frequency 0.09-µm GaN on 2-mil SiC research process.

Recently, preliminary HEMT devices fabricated in the 0.09-µm GaN were measured for small signal (s-parameter) and power performance (load pull). When these amplifier designs based on measurements at 24 and 32 GHz, plus extrapolations to 45 GHz, are returned and tested, the results will be used to verify the device measurements and validate any future nonlinear models for this process. Some of the additional designs, especially on the second die site, were based on guesses and extrapolations of current released devices (e.g., 0.15-µm HEMTs). Models are expected to be available in the future to validate the results of HEMTs used for other designs, such as low-noise broadband circuits and compact high-frequency oscillators directly fabricated in GaN. Additional reports on the designs using this 0.09-µm GaN process (2-mil SiC) will be forthcoming.

6. References

1. Penn J. 0.15 um GaN high dynamic range low noise amplifier microwave integrated circuit design. Adelphi (MD): Army Research Laboratory (US); 2012 Oct.

List of Symbols, Abbreviations, and Acronyms

ARL	US Army Research Laboratory
CRADA	cooperative research agreement
DRC	design rule checked
GaN	gallium nitride
MMIC	monolithic microwave integrated circuit
PA	power amplifier
HEMT	high-electron-mobility transistor
SATCOM	satellite communications
SiC	silicon carbide
SPDT	single-pull double-throw
TQS	TriQuint Semiconductor Inc.
T/R	transmit/receive
VCO	voltage-controlled oscillator

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